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SIMULATION OF THE INSECT ROBOT WALKING OVER LEVEL TERRAIN

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ABSTRACT
This paper presents a simulation procedure for generating a gait pattern and lateral motion sequence of a six legged robot. Gait pattern was studied and presented in the horizontal plane while lateral motion sequences were analyzed in the sagittal plane. Both analytical and graphical methods are used to study and to present gait and motion analysis over level terrain. Walking over level terrain demands particular gait selection, which is different from gaits for walking over irregular terrain. On one hand, restricting robot's motion onto level terrain can be seen as restricting mobility of the hexapod model by neglecting the gaits for irregular terrain and their properties. On the other hand, focusing on the level terrain gaits provides a chance for development of the model.
Finally, through Matlab® simulation, the usefulness of proposed simulation procedure is shown and results of the simulation are given.
Keywords: insect robot, hexapod locomotion, inverse kinematics

1. INTRUDUCTION
Robotics has achieved a number of great successes but one of the greatest to date is in the world of industrial manufacturing [8]. Industrial manipulators are able to move with great speed and accuracy performing all sorts of tasks, such as welding, painting, cutting etc. However, a major disadvantage of industrial manipulators is the lack of mobility [8]. They have restricted working volume due to the fact that they are being bolted to the fixed position. Compared to manipulators, a mobile robot would be able to travel through the manufacturing plant, flexibly applying its talent wherever it is most effective [8]. On the other hand, one may notice the usage of mobile robots in the environment where it is too risky to have human operator or even in the environment where humans are not able to work at all. Another example of mobile robot's usage is for humanitarian purposes [6]. Recently, mobile robots have been used in rescue missions of survivors at building crash sites after earthquakes [6]. These are the reasons why mobile robots are being intensively studied throughout years and why newer fields of their application are emerging on almost daily level.
Mobility is the most important charatheristics of mobile robots and it can be defined as an ability to move from one place to another in order to accomplish prescribed mission or task. A mobile robot needs a locomotion mechanisms that enable it to move unbounded throught its environment [8]. Mobility can be achieved using legs, wheels, caterpillars, tracks etc. as the means of locomotion [5]. However, only legs, wheels and caterpillars, as means of locomotion, can be completely used in an environment with obstacles [11]. On the other hand, compared to other means of locomotion, legged locomotion has a significant advantage over wheels and caterpillars, especially in rough and uneven

terrain [11]. Major advantage of legged robots is their adaptability and maneuverability as well as ability to isolate themselves from terrain irregularities. A walking machine which can travel where terrain difficulties make wheeled or tracked vehicles ineffective will be very useful in terrestrial applications in commerce, science, agriculture, military etc., and as a planetary rover [10].

In this paper, a brief introduction to ongoing research at Faculty of Mechanical Engineering University of Belgrade is presented. Paper provides the description of a walking problem, implemented simulation procedure as well as obtained results. At the end of the paper, conclusion and forthcoming research are given.

2. THE INSECT ROBOT MODEL AND SIMULATION RESULTS

The model of a walking robot with 18 degrees of freedom was considered. Model has six legs, each leg has three degrees of freedom, representing rotations, i.e. rotation around vertical axis in the hip (measured with angle α), rotation around horizontal axis in the hip which is parallel to the longitudinal axis of robot's body (defined with angle β) and rotation in the knee joint (angle γ). A leg of a model with joint angles is given on the Figure 1. Note that in general an insect's leg could have more than five degrees of freedom [3]. Model is feetless, so contact with the ground of leg *i* is approximated with point contact. Impact of a leg *i* with the ground, after finishing transfer phase and on the beginning of the support phase, is idealized as well, to insure velocity continuity [11]. Basic definitions of gait analysis are not given since thorough analysis can be seen in [10].

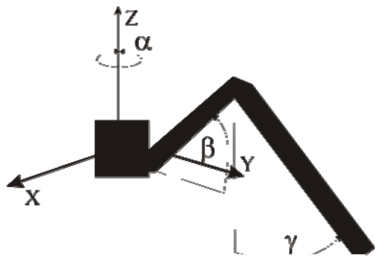


Figure 1 . Degrees of freedom for a leg

2.1. Trajectory generation

There is a number of developed methods for trajectory generation of insect robot. One of the popular approaches to trajectory generation problem of the insect robot is mimicking the animal (in this case live insect) trajectories. Insects are filmed while walking on a treadmill, and afterwards, filmed movements of the limbs are analyzed and implemented in walking machine. Laksanachoren [4] studies cricket walk and uses these extract experimental data to solve inverse kinematics. This kind of solving technical problem while "stealing" solutions from nature is called *biomimetic* approach. On the other hand, Cruse et al. [3] developed decentralized control of insect robot leg movement based on artificial neural networks called *Walknet* [3]. Controller uses raw experimental data extracted from stick insects during walking on the treadmill and generalizes over unknown input data. Although controller has strictly kinematical approach to leg movement generation while dynamical effects during walking have been neglected, it is still able to generate desired movements. Main advantage of this method is in decentralization of mechanisms that govern leg movement, which enables each controller to have full control over a particular leg. The essential idea is not to track the recorded trajectory of the reference point in the real time but to stimulate controller of each leg to decide when to start moving the leg or whether the movement of the leg should occur at all [11]. One of the more important principles introduced in this controller is the idea of positive feedback during the support phase [3]. Implementation of a *Walknet* in a real walking machine is in progress [3].

In this paper, trajectories of the robot's feet are defined in the Cartesian space and based on this idea the inverse kinematics of each leg was solved. It was assumed that the shape of feet trajectories is cycloidal function, which is defined as:

$$\{r_{fi}\} = [x_{fi}\ y_{fi}\ \ z_{fi}]^T = \left[V(t - \frac{T}{2\pi}\sin(\frac{2\pi t}{T})) \qquad y_{fi} \qquad z_{\max}(1-\cos(\frac{2\pi t}{T})) \right]^T \tag{1}$$

where, V is the forward velocity, T is the cycle period and z_{max} is maximal elevation of a foot during transfer phase. Similar approach to the issue of trajectory generation can be seen in [9,11] but with completely different leg configuration. In order to solve inverse kinematics the trajectory of the robot's center of gravity has to be known parameter. It is assumed that robot is traveling with constant forward velocity and constant height measured from the ground, which yields to these equations:

$$\{r_{hi}\} = [x_{hi}\ y_{hi}\ \ z_{hi}]^T = [Vt\ \ y_{hi}\ \ \ H]^T \tag{2}$$

where t is time, H is a height of the center of mass and V is the velocity of a robot. It was assumed that robot moves along a straight line without changing direction. The velocity can be defined as:

$$V = R / \beta T \tag{3}$$

where R is the leg stroke, the distance the body travels in a period in which foot of a leg is in contact with the ground, β is the duty factor and T is the cycle period [10,11]. The lateral movements of the insect's body are being neglected, i.e. $y_{hi} = const.$ for now.

After defining trajectories ot the center of the mass and of the foot of a leg, joint angles α, β, γ could be obtained. The formulation of inverse kinematics is given as [11]:

$$\{r\} = \{r_{hi}\} - \{r_{fi}\} \; ; \; \{r\} = f(q) \Rightarrow \{q\} = f^{-1}(r) \tag{4}$$

where q is a vector of joint angles of a leg i.

On Figure 2. one may see formulation of basic geometrical characteristics.

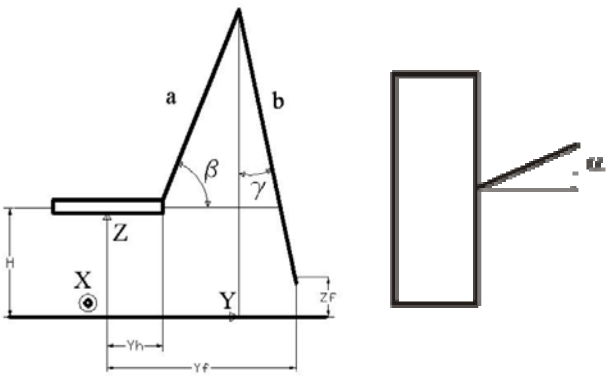


Figure 2. Insect's robot leg during transfer phase (front view and top view)

Analytical relations among parameters are easily established:

$$\begin{aligned} y_f - y_h &= (a\cos\beta + b\sin\gamma)\cos\alpha \\ H - z_f &= b\cos\gamma - a\sin\beta \end{aligned} \tag{5}$$

These equations are important for gait in order to achieve coordination among leg angles and to harmonize their changes in a time period in support phase as well as in the transfer phase.

2.2. Simulation results

In order to test a procedure, a simulation has been performed in *Matlab*® and the results of one simulation will be presented here. According to the basic definitions of gait analysis [10], the phase of leg i ϕ_i, the time instant which defines when observed leg supports the body and when it leaves the ground, can be obtained provided that a particular gait and duty factor β are known parameters [9,10]. In other words, time instant when transfer phase finishes and support phase occurs are completely defined. Of course, *vice versa* holds as well.

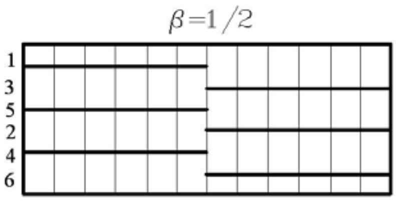
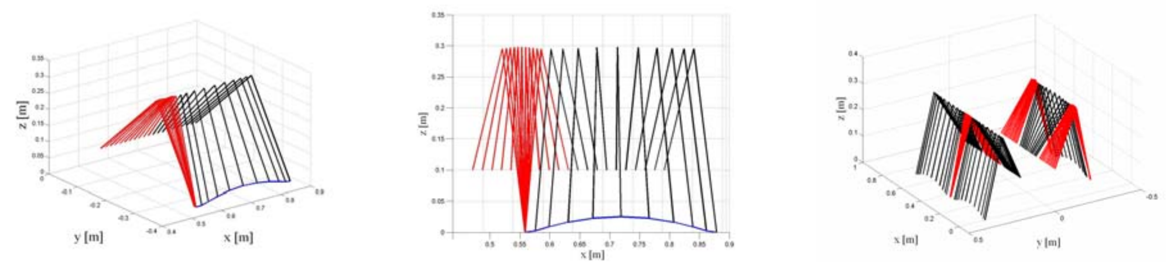


Figure 3. Gait diagram for a tripod wave gait

It is well known fact that on flat terrain periodic gaits should be used [10]. Having this in mind, tripod wave gait was chosen for a purpose of a simulation. Compared to other types of wave gaits, tripod wave gait is the fastest [7], due to the fact that each leg spends same amount of time in support phase and in transfer phase. From the standpoint of stability, wave gaits have optimum stability during walking [10] and these gaits can be used for walk on flat terrain in straight line [7].

Two different approaches were chosen, although results of only one simulation will be presented since simulation results are similiar . In first model, it was assumed that robot's leg travels along a constant lateral distance relative to robot's body. In other words, y coordinate of a leg's reference point (a foot) is constant while x and z coordinates are defined according to equation (1). The position vector of the hip of leg i changes according to (2). Using the inverse kinematics formulation (4), values of joint angles α, β, γ can be obtained. In second model, y coordinate of a leg's reference point has a circular trajectory relative to the i-th hip, i.e. the foot of the leg travels along constant radius. On Figure 4 one may see the stick diagram, which is diagram of consecutive positions of the leg i during the support phase as well as the transfer phase.



a) b) c)

Figure 4. Stick diagrams: a) for one leg isometric, b) one leg in the sagittal plane, c) all six legs

3. CONLUSION

The model of walking robot with 18 degrees of freedom was introduced. Based on defined trajectories of the ***i***-th foot as well as ***i***-th hip, the inverse kinematics was solved, simulation in *Matlab*® was performed and results were presented. Periodicity of leg movements had been assumed and a particular gait sequence was chosen. However, from the standpoint of high mobility and autonomous behaviour, specific and accurate trajectories are not of importance during walking. Although presented approach has restricted possibilities for *real time - real environment* implementation, it still provides a chance for development of the model which is an important base for forthcoming research. A complete derived analytical model of insect robot gait does not guarantee stable and successful gait in the real world where characteristics of terrain and environment are dominant factor of influence on behaviour as well as gait [1,10]. In order to overcome this problem, various methods have been developed, improving generation of movements in the real environment. One possible solution for this problem may be in increasing the level of robot's selfawareness and autonomy. According to the definition of autonomous system [3,5], the system (walking robot in this particular case) would be able to percept and understand changes in the environment and act as an intelligent creature. On this basis, as it was stated in [1], "a mobile robot would use the world as its own model"**.** Having previous analysis in mind, a proper implementation of artificial neural networks is being considered in order to use results obtained by this simulation and forthcoming ones as learning pairs for development of a system that would control leg movements.

4. REFERENCES

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